

**MICROCALORIMETERS WITH NTD AND EXPITAXIAL GERMANIUM  
THERMISTORS FOR HIGH RESOLUTION X-RAY SPECTROSCOPY**

NASA Grant No. NAG5-5269

Progress Reports Nos. 3 and 4

For Period 7 April 2002 through 6 April 2004

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April 2004

Prepared for:

National Aeronautics and Space Administration  
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The Smithsonian Astrophysical Observatory is a member of the Harvard-Smithsonian Center for Astrophysics
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**Progress Report  
NASA Grant NAG5-5269**

**Microcalorimeters with Germanium Thermistors for High Resolution Soft  
and Hard X-ray Astronomy**

**March 31, 2004  
Submitted by E. Silver et al.**

**1. Introduction**

This is a progress report for the second year of a three year SR&T grant to continue the advancement of NTD-based microcalorimeters. We reported last year that we re-prioritized certain aspects of the statement of work and chose to emphasize issues of array development in the first year rather than wait until year two. Consequently, some of the projects scheduled for the first year were delayed to the second year and we report on those topics here. These include:

- a) Measurements that map out JFET , thermistor,  $1/f$  and feedback resistor noise;
- b) Investigations that evaluate the limits of the JFET preamplifier circuitry as it pertains to stability at the 2 eV level;

The results of a) and b) have led to preliminary measurements that demonstrate 3.08 eV resolution at 6 keV.

- c) Calculations that can predict the current performance.

**2. Noise measurements and JFET preamplifier Stability**

We have carefully evaluated the noise contributions from the feedback resistor and the JFET in the negative voltage feedback circuit. A special, AC grounded gate, preamplifier was built to measure the noise of the in-situ JFET independent of the feedback resistor. Figure 1 is a plot of JFET noise vs frequency for a JFET operated with several different amounts of drain current. By reducing the drain current below 1 mA, we were able to significantly reduce the low frequency noise ( $1/f$  noise) while incurring only a modest rise in the higher frequency noise. However, the JFET transconductance, already modest at higher currents, dropped a further factor of two when the drain current was reduced to the lower levels consistent with the desired low frequency, low noise operating point. The open loop gain, which was never large for our preamplifiers, was also reduced a further factor of two. This reduction in open loop gain ( originally  $\sim 2000$ ) caused us to reconsider the issue of virtual ground stability and dynamic impedance. Our solution, an entirely new preamplifier topology, overcomes the limitations of our previous preamplifier. The new preamplifier has an open loop gain  $\sim 100,000$  when the JFET is operated at a reduced drain current consistent with low noise at low frequencies. With the large open loop gain associated with this revised preamplifier topology the issues of virtual ground dynamic impedance and stability are gone. Serendipitously, the new preamplifier topology also requires less power and has fewer components.

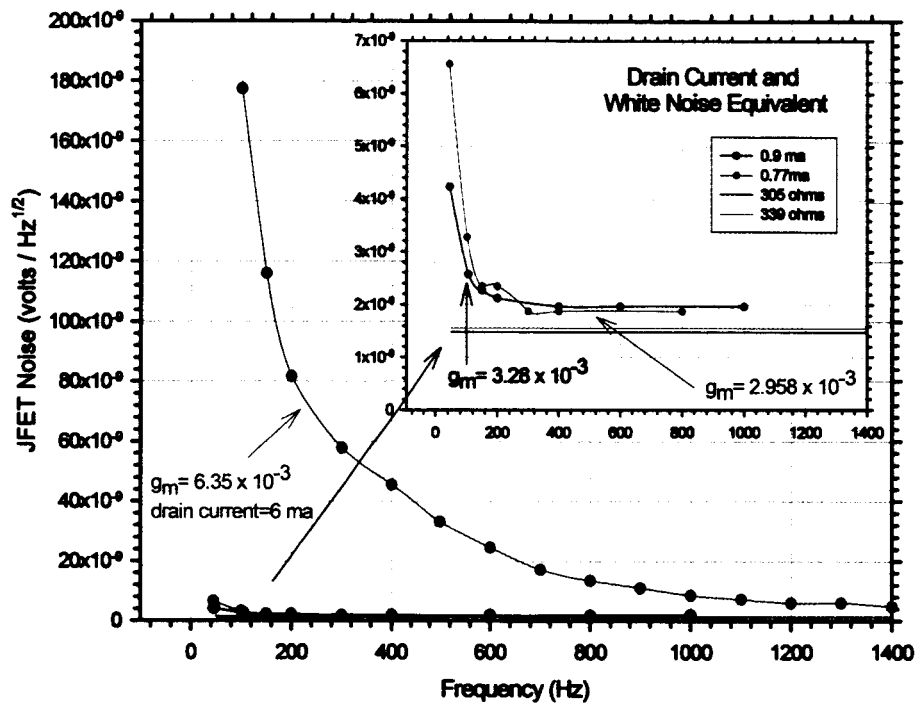


Figure 1. The JFET noise as a function of frequency for three values of drain current.

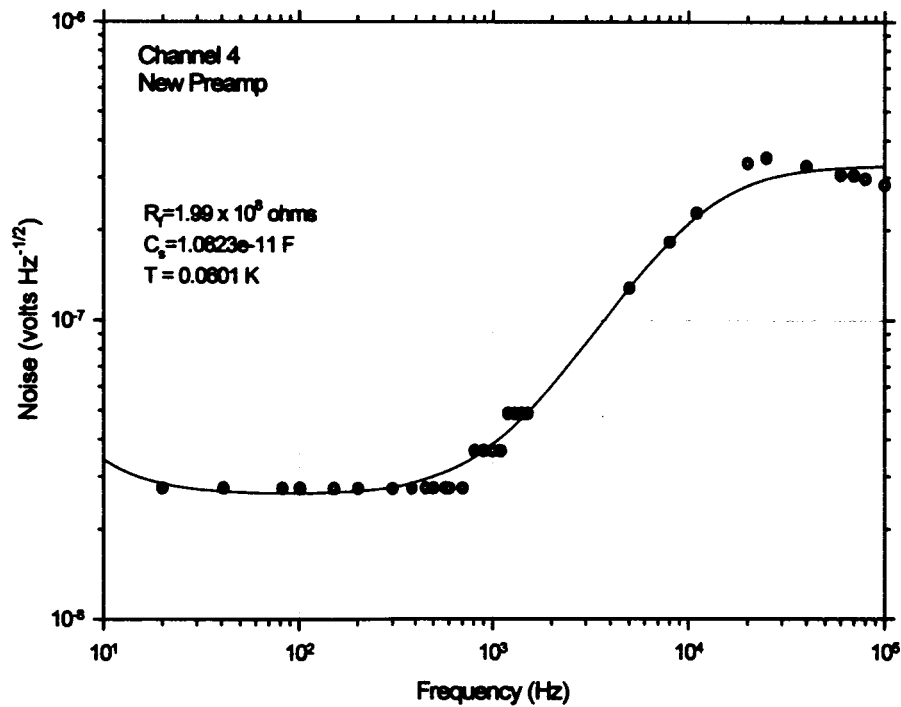


Figure 2. The combined noise of the JFET and feedback resistor; blue dots are the measured values and the black curve is the theoretical fit. The detector's thermistor is not included in these measurements.

An additional set of measurements were performed to verify that the combined noise from the JFET and feedback resistor was what one expected from theoretical predictions. In Figure 2 data is plotted in blue and a theoretical fit (black curve) based upon the measured feedback resistance and capacitance values, circuit stray capacitance and independent JFET noise measurements (from Figure 1).

Not only do these results show that the circuitry is now well understood, but the preamplifier circuitry produced immediate improvements in the performance of our NTD germanium microcalorimeters. In Figure 3 we plot the spectrum of the Mn  $K\alpha$  and  $K\beta$  lines from the an  $Fe^{55}$  radioactive source. The expanded view shows  $K\alpha_1$  and  $K\alpha_2$  natural line shapes in red and the microcalorimeter's measurement in blue. The microcalorimeter resolution is  $3.08 \pm 0.23$  eV. To achieve this resolution we have to maintain a temperature stability of  $< 5$   $\mu$ K (we achieve 1  $\mu$ K) and a stable JFET operating temperature which influences the stability of the gate voltage..

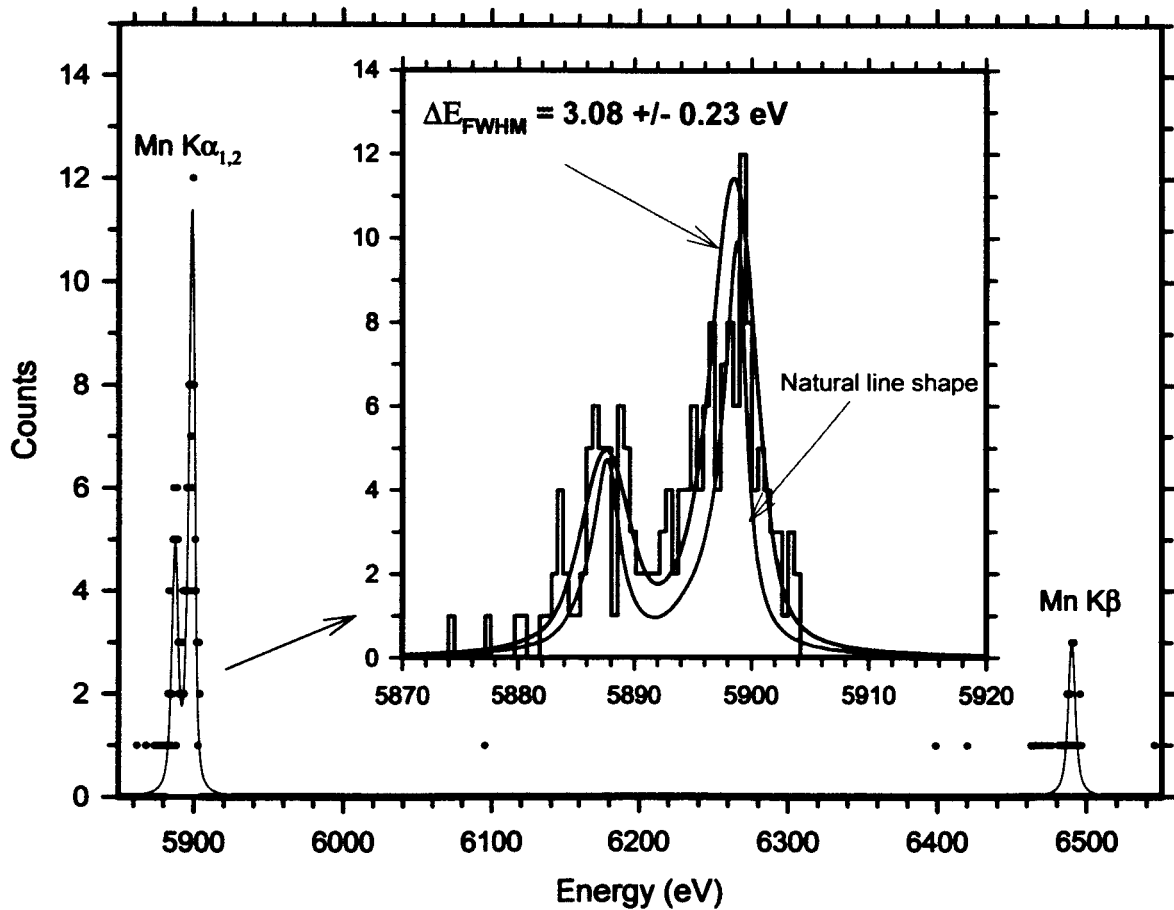


Figure 3. Our most recent microcalorimeter measurement of the K lines from a  $Fe^{55}$  radioactive source. The expanded view shows the  $K\alpha_1$  and  $K\alpha_2$  natural line shapes in red and the microcalorimeter's measurement in blue.

### 3. Theoretical Calculations

We have developed a model to predict the performance of our NTD microcalorimeters. In Figure 4 below we plot the contributions to the total noise in units of eV as a function of energy for the microcalorimeter used to measure the spectrum in Figure 3. The value of the thermistor resistance at 58 mK and zero bias is  $2 \times 10^7$  ohms. The bias current is  $7 \times 10^{-11}$  amps and the FET noise is  $2 \times 10^{-9}$  volts/Hz<sup>1/2</sup>. The largest contribution to the noise below 10 keV comes from the thermistor followed by the phonon noise and FET noise. We point out that the resolution increases with energy because in the constant voltage configuration used in our preamplifier, the thermistor noise current goes as  $1/R^{1/2}$  and the FET noise expressed as an input current goes as  $1/R$ . Since the thermistor resistance decreases as the microcalorimeter absorbs the energy of an x-ray, these noise components will increase. The phonon noise also increases because it reflects the microcalorimeter temperature during an x-ray event. We define the noise during the x-ray pulse as *dynamic* noise and distinguish it from the *static* noise which is characteristic of the microcalorimeter in the absence of x-rays. The feedback resistor does not have a dynamic noise component. This model describes the performance of our microcalorimeter at 6 keV quite well and also predicts that the resolution should be 1.7 eV at 1 keV. We have yet to measure this and now recognize that there is a noise after the preamplifier stage that is a limiting factor. We will investigate the source of this noise during the next year.

In Figure 5 we predict the performance for a modest change in detector parameters. With a slight decrease in JFET noise and a modest increase in current bias, a resolution of  $\sim 2$  eV at 6 keV can be achieved. We will also pursue this work during the next year.

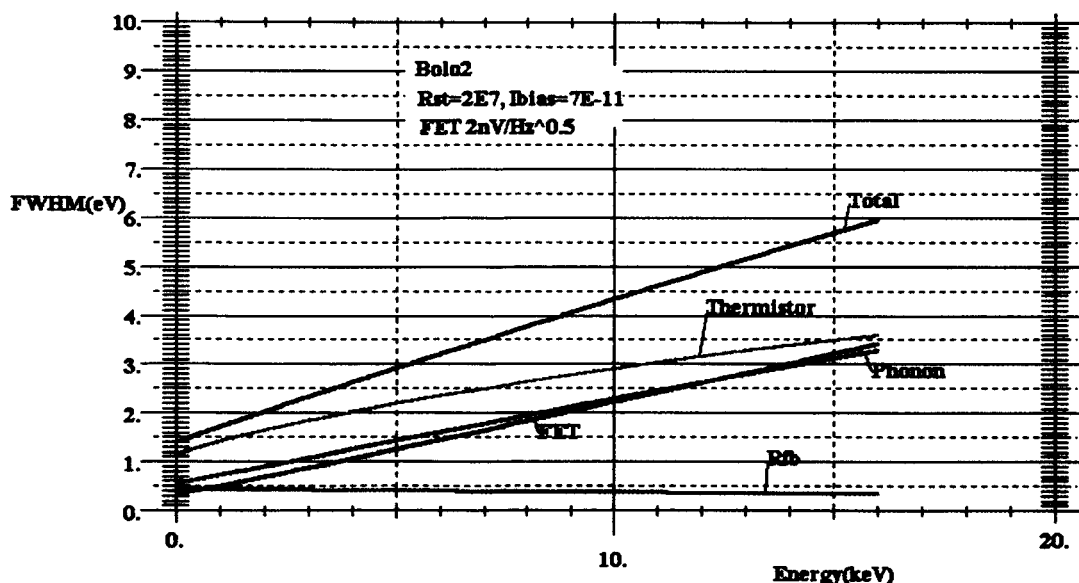


Figure 4. The calculated noise contributions to the total noise of the detector used to measure the spectrum in Figure 3. It is consistent with our measurement of 3 eV at 6 keV and predicts 1.7 eV at 1 keV.

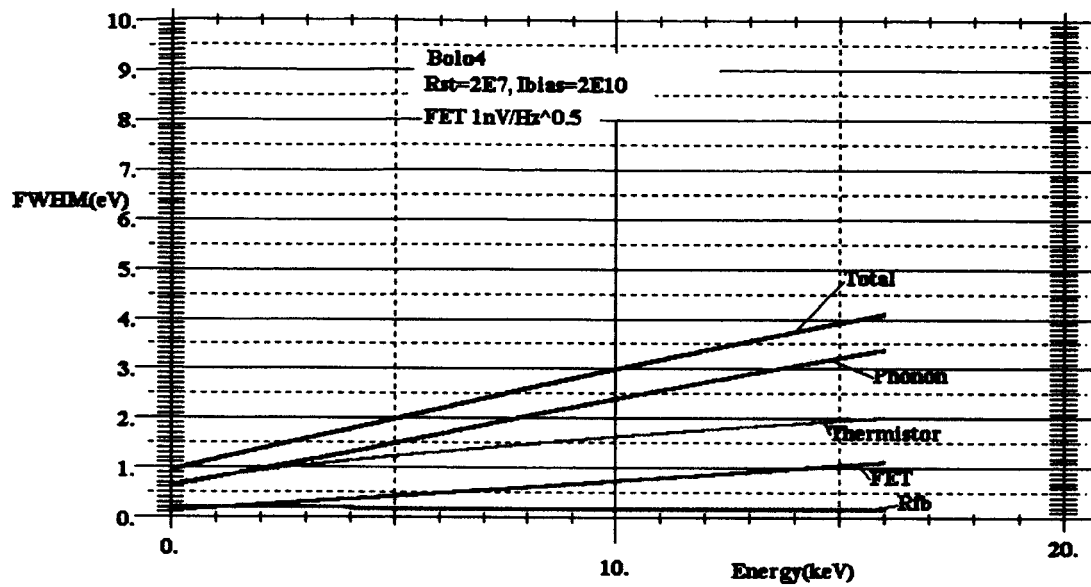


Figure 5. The calculated noise contributions to the total noise for a modest change in detector parameters from those of Figures 3 and 4. It predicts 2.2 eV at 6 keV and 1.2 eV at 1 keV.